DRAFT - Risk Management at the Total Project Level
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INTRODUCTION

Objectives of Risk Management on Flight Projects

Flight Projects plan their work against challenging technical objectives and tight schedules, and in the new environment of Faster-Better-Cheaper, low, rigid budgets. With these difficult budget limits, managers striving for high confidence in a successful outcome are constrained from using methods that worked in the past, such as excruciating attention to technical detail, exhaustive testing, extensive what-if exercises which flushed out every conceivable problem and fixed it. These methods, though thorough, depended on the ability to increase the budget from time to time to be able to throw the needed resources at each problem that was uncovered.

In today's project environment, a process of balancing the reserves and margins in technical performance, design commodities (like system mass, power, etc.), cost and schedule reserves, is needed to weather the inevitable storms and setbacks that are normal to space system development projects, to arrive at a successful project result.

Risk Management is such a process. It involves recognizing that each project has both "ordinary" potential for unforeseeable adverse events (so-called unknown unknowns) and "extraordinary" characteristics, with associated potential knowable unknowns. By recognizing these knowable risks, assessing them in a meaningful way, and utilizing the resources and resource margins available to them, project managers can develop some measure of confidence that they will withstand these "known" risks. Thus they will have an assessment of the margin remaining to cover inevitable non-predictable adverse events.

Supporting Risk Management at JPL

Within the JPL Process-centered approach to developing challenging space flight missions, Risk Management is supported at JPL through an office in the Engineering and Mission Assurance Directorate (EMAD). The Risk Management process establishes requirements on Flight projects that basically steer them toward compatibility with NPG 7120.5A, in which NASA defines tailorable requirements for Program and Project management. The process also provides methodology, tools and training which are

tailorable by the program/project, to accomplish the unique requirements/plans they set out for themselves. This process is supporting today's projects and programs, while at the same time being integrated with the new product delivery process at JPL.

The current program/ project environment at JPL is defined by many small but highly visible projects, where, not too long ago, there were only a few large (also highly visible) projects. Characteristics significant to Risk Management include:
a) program management moving from NASA towards JPL,
b) formalism and independent review represented by the NASA process-centered approach to program and project management, and
c) project teams which are stretched by the small budgets and large workloads.

This paper describes briefly JPL's approach to implementing the risk management process in this environment. We will discuss some of the current approaches to dealing with managing constrained resources. Finally we will consider some ideas of where it might be made more helpful.

APPLICATIONS OF RISK MANAGEMENT IN JPL PROJECTS

Two Approaches to Risk Management

Risk Management at JPL was prototyped by two projects – Mars Global Surveyor (MGS), and Space Infra-Red Telescope Facility (SIRTF). Each project implemented risk management in a different way. These two prototypes are being copied or closely modeled on other flight projects. The Risk Management process team is also using the tools and methods developed for these projects to evolve a general approach that is sufficient as a standard for projects, while also providing tailorable features to meet specific needs.

The MGS Risk Management approach used the tools of project management and technical assessment to find and fix mission-threatening design issues. The major concern on this fixed-price mission utilizing proven designs and hardware was whether there was sufficient budget reserve to get to launch. The risks identified were focussed on adverse impacts that would require the use of budget reserves to remedy. The risk consequence and the likelihood of occurrence were assessed in a quantitative sense as an estimated cost to remedy the occurrence, and a probability of occurrence. Mathematical calculations could then be used to assess total project risk as a measure of adequacy of the budget reserve.

The SIRTF approach is to not use numerical risk ratings for either likelihood or consequence of occurrence. Rather the risks are evaluated on a qualitative rating of negligible, low, significant, and high, with criteria developed for the levels of impact to the mission requirements and/or the threat to the budget reserves. Primary risks are then those risks evaluated as significant or high in likelihood and consequence. These risk drivers are then extensively analyzed for the most effective mitigation, which is applied to drive the risk to a lower level.

Elements of both of these approaches are included in the current risk management approach at JPL, and are extrapolated in a quantitative approach to total project risk management, which we are developing, and which is the main topic in this paper.

RISK MANAGEMENT METHODOLOGY

Planning – Setting objectives, defining resources to be managed

The basic element of total project risk management is understanding the critical resources of the project, and establishing the risk assessment criteria around them. This understanding comes from the project **Concept Baseline** definition process, in which the design and implementation approaches are defined, and confidence in achieving the success objectives within the resources available is demonstrated. From this, approval to enter the formulation process is given. This concept baseline definition process is illustrated in figure 1.

Figure 1 -   The Concept Baseline Definition Process
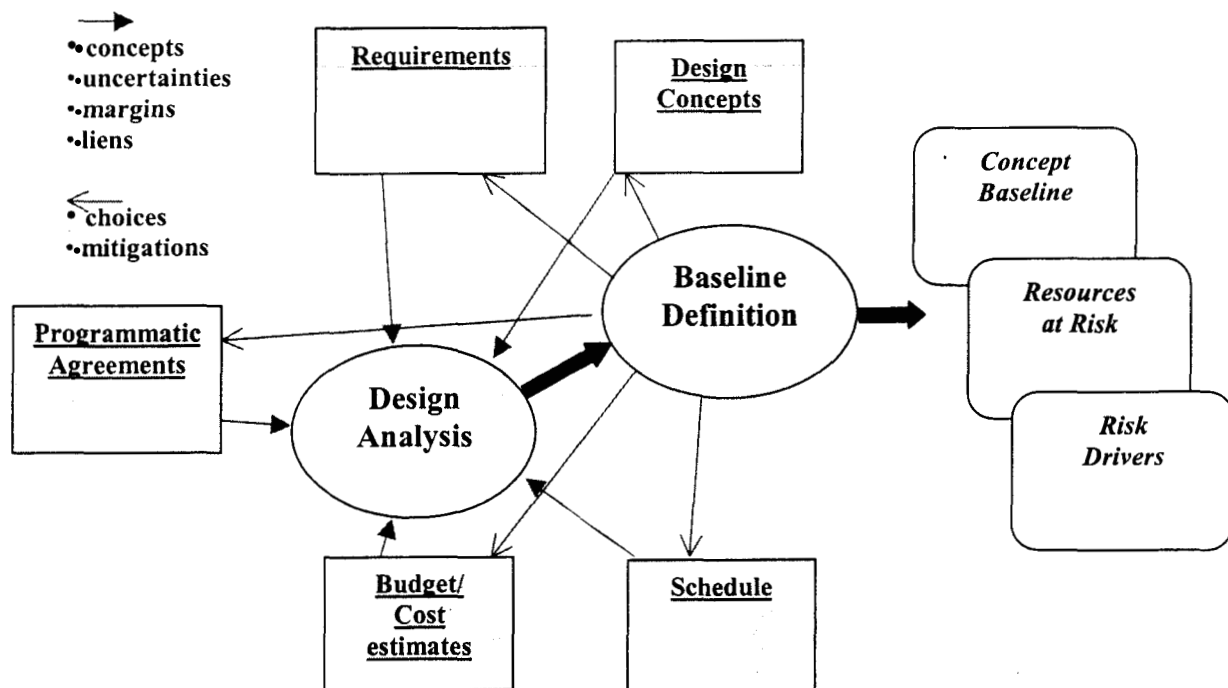
The concept baseline is an input to the project planning process. A preliminary design and implementation budget and schedule are the outputs, but from a Risk Management perspective, the key outputs are the identified risk drivers, and the project resources critical to successfully managing those risks.

Identifying Risk Items

A risk is defined as a combination of the consequences of occurrence and the likelihood of occurrence of an identified potential adverse event. A **risk item** consists of the descriptors and assessment data for this risk. The essential elements of risk identification are:

Project Team Identifies and Assesses Risk Items

The best insight into the effort resides in the technical and administrative experts doing it. This "Expert Judgment" is asked to look into all aspects of the work with some structured guidance to identify potential future adverse events. All areas of the work - technical, cost, schedule, programmatic, etc. are examined. They draw on many sources - experience, analyses, lessons learned, etc. In addition, comprehensive analyses such as failure mode effects analyses, schedule and budget uncertainty analyses, etc. might be used to flag risk areas based on an accumulated institutional or even industry experience bases.

Implementation and Mission Risk Aspects of a Risk Item

As exemplified above, consequences can have different forms, and two aspects. We differentiate between the aspect of risk dealing with the threat to implementation resources – which we call **Implementation Risk** – and the threat to mission performance and hence to mission success – called **Mission Risk**. Each Risk Item will be assessed in both aspects.

Risk Item Data Requested

For each risk item, the experts and/or the "risk owners", are asked to identify approaches (called **"mitigation" options**) which the project should consider to effectively reduce exposure to the identified risks. These are measures not currently in the baseline plan. They may be executable immediately, or have planned decision milestones identified. Other information required is a **reassessment of the risk** presuming that the mitigation option is exercised. These and other suggested data entries for each risk item are shown in table 1.

Table 1 - Risk Item Data

Title/ ID No.
Description/ Root Cause
Possible Categorizations
     Project Source Element (e.g. System/ Subsystem, Interface, where the risk is primarily centered)
     Cause Category (e.g. new technology, programmatic, cost, schedule)
Risk Owner
Implementation Risk Assessment (Budget, schedule slack, technical margin(s), etc.)
     Likelihood
     Consequences
Mission Risk Assessment
     Likelihood
     Consequences
Mitigation Options
     Descriptions
     Costs
     Change to the assessed risk
Significant Milestones
     Opening/ Closing of the Window of Occurrence
     Risk Change Points
     Decision Points for Mitigation Implementation Effectiveness

Defining the Assessment Criteria

The project must define criteria for assessing the likelihoods and consequences of risk items. The metrics of the consequences should reflect the critical project resources identified in the concept baseline, and the threat to technical performance in the mission.

A couple of **examples** follow:

a)   On project A, the lead procurement items are not yet defined, which puts the schedule at risk, and the technology assumed in the design provides a spacecraft mass with less margin than is expected at this stage of development. **Schedule** and **mass** margins are therefore two threatened resources, and risk will be assessed against these as criteria, at a minimum.

b)   On project B, the radiation environment exceeds the tolerance of the backup design, which is being carried due to the technology maturity uncertainty of the primary approach. **Mass** is at risk because of the unknown shield mass requirements, **schedule** is at risk due to the uncertainty in the new technology, and **budget** is threatened due to these aspects, and the technology itself. **Mission success** is at risk because the degradation in performance over time in the mission of the primary approach may shorten the mission life.

These characteristics of the concept baseline lead us to the resource criteria we choose to assess risks, which the project will identify. For the case b) above, the risk criteria might be as shown in table 2.

Table 2 - Example Risk Consequences Assessment Criteria

Conse-quence Rating	Mission Risk	Implementation Risk		
		Mass	Schedule	Budget
High	Most of the Level 1 requirements would not be met	Resolving the occurrence would require most of the remaining system-level mass margin	Resolving the occurrence would require most of the remaining slack in the critical path	Resolving the occurrence would require most of the remaining project budget reserve
Significant	One of the Level 1 requirements, or most of the level 2 requirements would not be met	Significant impact to system-level margin	At least 20% impact to the slack on the critical path; Would require most of the sub-system schedule slack	At least 10% of the unencumbered project budget reserve.
Low	1 of the level 2 requirements would not be met	Requires most of sub-system mass allocated margin	Significant impact to subsystem delivery slack	Significant impact to allocated subsystem budget reserve
Negligible	Performance would be degraded, but all requirements still met	Resolvable within the subsystem allocated margin	Resolvable within existing schedule slack	Resolvable with no impact to system budget reserve

Qualitative Risk Item Assessment

The qualitative approach uses adjective ratings for the consequences of a risk item, as described earlier, and exemplified in table 2. Adjectives are used to assess the likelihood of occurrence as well.

Qualitative Risk Magnitude

The magnitude of the risk (i.e., the method for combining likelihood and consequence) can be represented as the length of the risk vector on the familiar graphic illustrated in figure 2. The risks can be "binned" and compared with other risks, also shown in figure 2. This works well for highlighting the project risk situation, but the data are less amenable to performing trade-offs among competing mitigation strategies.

Figure 2 - Qualitative Risk Assessment

Risk Item "i"
Magnitude

Mitigation Effect

Risk Magnitude

Increasing Risk

H

Likelihood   M

L

L   M   H

Consequence

Risk Magnitude Bins

H

M

L

L   M   H

Risk Matrix
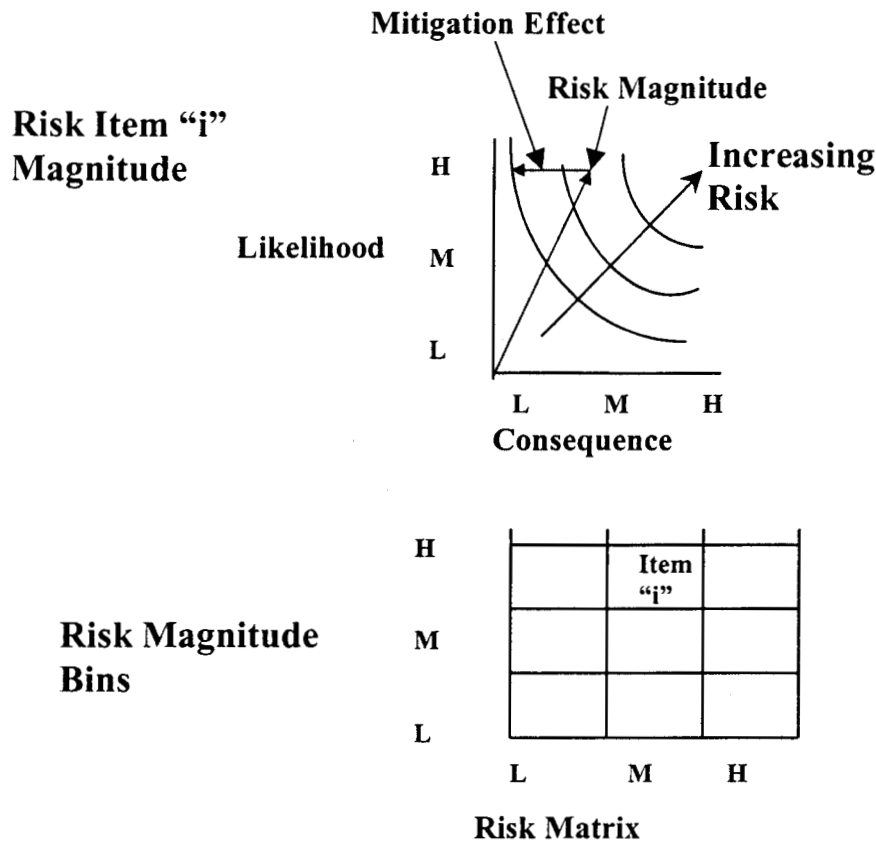
Quantitative Risk Assessment

Quantitative assessment replaces the adjectival rating with a numeric value, for both consequence and likelihood. There are two ways of doing this – the assignment approach, and the grass-roots approach. **Assignment** is an extension of the qualitative method –if the criteria for a medium likelihood assessment were "probability of occurrence between 10% and 50%", an assignment of p=0.3 would "quantify" a medium likelihood. For a "quantification" of the risk to the mass resource example of table 1, an assigned quantification might be as shown in table 3.

Table 3 - Assigned Quantification of Risks - Example

Consequence Rating	Mass	Cost – (% Remaining mass margin)
High	Resolving the occurrence would require most of the remaining system-level mass margin	50
Significant	Significant impact to system-level margin	10
Low	Significant impact to sub-system mass allocation	1
Negligible	Resolvable within the subsystem allocation	0.1

The **grass-roots** method of quantification is to ask the risk assessors to estimate an impact value, generally by asking them to hypothesize the impact to the resources to "fix" the product in the instance that the risk occurs. This may mean a new design, or changing the existing design, with attendant impacts on several managed resources. These impacts become the quantified risk consequences, as illustrated by the example risk described in table 4.

Table 4 - Grass-Roots Quantification of Risk - Example

Risk Description	Response/ Fix	Mass Impact		Budget Impact		Sched. Impact	
		(kg)	%	($K)	%	(days)	%
Light-weight structure will fail the qualification test	Add stiffeners throughout the structure	75	12	200	3	14	25

Note that budget resource impacts can and sometimes are estimated by Fiscal Year if the risk scenario supports such an assessment.

Quantitative Risk Magnitude

The methodologies proposed here for practical use make generally useful assumptions about independence of the risks, so that the combination methods simple. If the risks identified are highly correlated, this method must be augmented or at least recognized for the inaccuracies it produces. Figure 3 shows the simplified mathematical risk magnitude calculation obtained by multiplying the resource impact by the probability of occurrence, for each resource impacted by each risk.

Figure 3   Quantitative Risk Assessment

Risk Item "i"

Likelihood: - Measured from 0 to 1
(from "no way" to "for sure") - p_i
Consequence: - Measured as a percentage of impact
on k_{th} Project Resource Element - I_{ik}

- Implementation Risk Resource metrics
1- budget reserve ($ by FY and/or total),
2- schedule margin (days),
3- power margin (w),
4- mass margin (kg)
- Mission Risk (impact on mission success (%))

Risk Magnitude: - product of likelihood and consequence- $p_i x I_{ik}$
(e.g. prob. of risk is 0.5, and cost to fix it is $1000 - risk cost magnitude is
$500)

Mitigation Approaches

For each mitigation approach identified, we assess its cost in the same resources we assessed the risk. If we exercised the mitigation approach, what would it cost in terms of those resources? Also, connected with that mitigation approach, one or more risks would be reduced. The reduced risks must also be reassessed (i.e., would the new risk impacts be eliminated or reduced, and/or would new but lower risks be introduced?)

Combining Risks

In order to see the total risk position for the project, we must consider the aggregate of the risk items, or the total impact of all identified risks on the project. For this we first look at risk aggregation using the qualitative assessment method, and then the potentially more powerful and decision-oriented quantitative approach.

Qualitative Total Risk Assessment

Figure 4 illustrates the graphical "risk matrix" aggregation of risks. The risk management strategy would define the approach to handling risks in each sector of the risk matrix. The different color zones are a primary strategy feature. Risk in the red zone would be primary risks in NPG 7120.5A parlance and must be reduced or justified by quantitative arguments which show that acceptance is the minimum mission success risk and an acceptable implementation risk. Risks in yellow may be individually tracked, with mitigation plans, while green risks are watched only to make sure they don't move into yellow or red.

Figure 4 - Qualitative Total Risk

Project Total
Risk Position:

	L	M	H
H	(4)	(0)	(0)
M	(16)	(6)	(2)
L	(30)	(10)	(2)

Risk Matrix

Quantitative Total Risk Assessment

The total project risk can be assessed, again with reasonable assumptions about independence, by adding the risk magnitudes of all risk items in each resource or implementation risk criteria. These are in effect "expected" impact values, which can be added as shown in figure 5 to obtain total project risk estimates for each of the resources

being managed. The total risks in each resource can be compared to the reserves in that resource as an estimate of the confidence that the reserves will be sufficient.

Figure 5 -   Quantitative Total Risk

Project Total Risk Position (R)

- For each resource (consequence) category (k), probabilistic sum of $p_i x I_{ik}$ over (i)

(For most practical cases, can assume risks and consequences
are independent and therefore
R=[sum over all i] $p_i x I_{ik}$)
(e.g. total project risk cost is sum of risk item risk costs)

The Trade-Off and Decision Process

Trade-offs will include assessments about the degree of mission risk the project is willing to assume, and will select first the mitigation options which provide reduced risk to that criteria. Then further trade-offs will be conducted to balance the implementation risk among the critical resources.

Figure 6 illustrates the trade-off process to examine promising mitigation actions.

Figure 6 -   Quantitative Risk Assessment - Trade-off Process
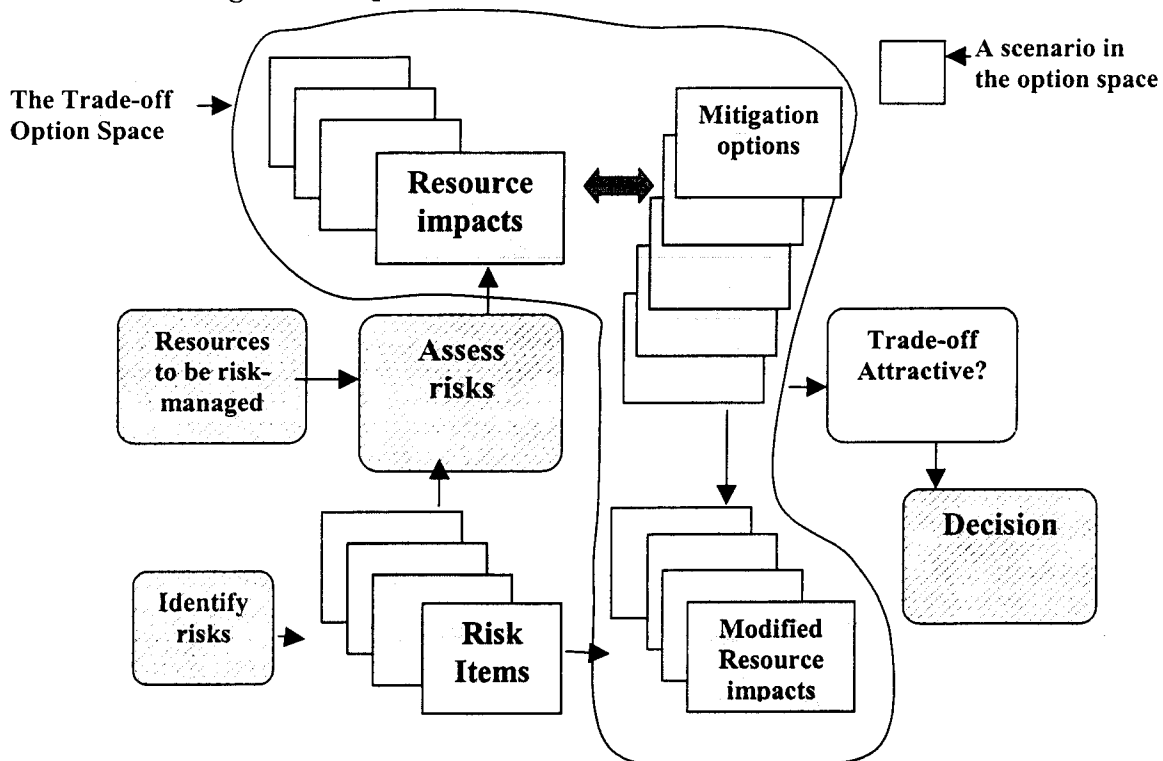
In a relational data base, each risk item is related to one or more possible mitigation actions, and each possible mitigation action is related to one or more risk item. Therefore, to see effective mitigation strategies, one can select subsets of the possible actions, and calculate the change to the resources at risk if the actions are taken. Thus, the risk position after the action is the sum of the costs of the actions plus the new project risk position, as defined by the risk reduction assessments associated with those mitigations. Comparing the current total project risk (before mitigation) with the post-mitigation total project risk (as illustrated in figure 7) will allow identifying the mitigations most effective in controlling the resources being managed.

Usage of the Quantitative Methodology

This method of aggregating quantified risk was introduced, as mentioned above, on the Mars Global Surveyor Project, for managing budget reserve. The extension to other

Figure 7   Quantitative Risk Assessment - Decision-Making Process
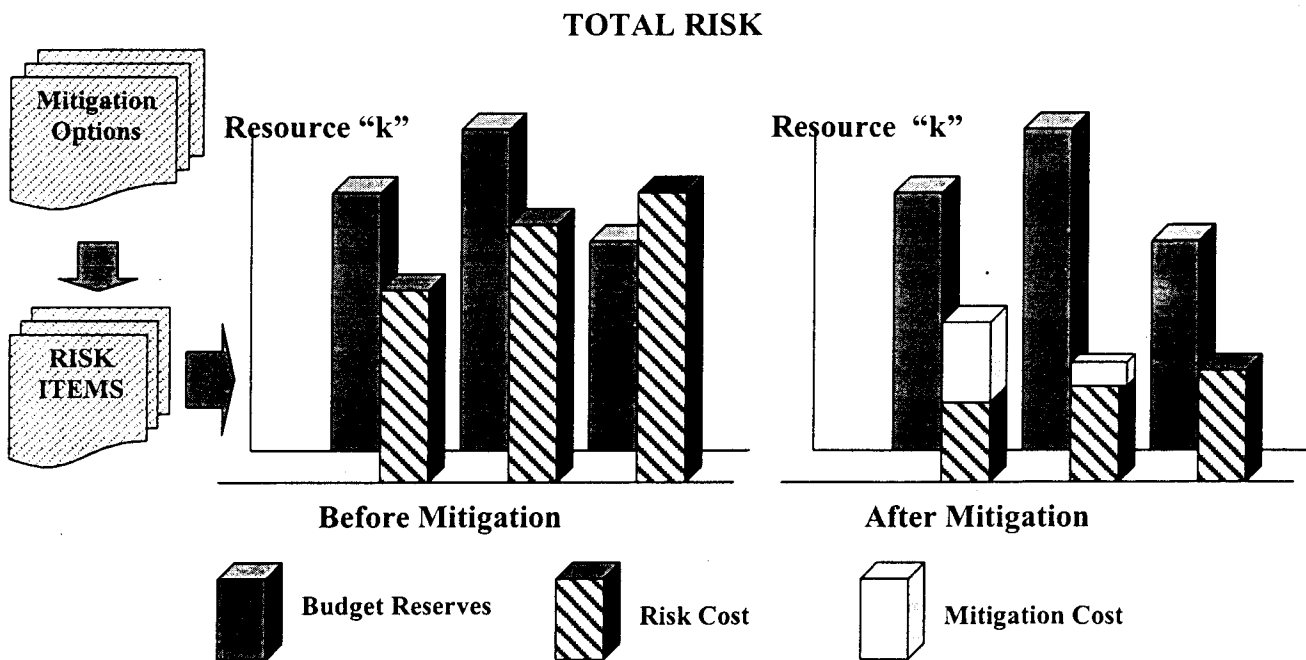
resources of significance to the project has not been applied at JPL yet. The insight gained by MGS and the appreciation for the utility of the method by NASA are encouraging us to make this refined method sufficiently easy to use that projects will adopt it.

Tracking

While not dwelling on this aspect of Risk Management, we should be remiss not to mention the necessity for watching risks throughout the project life-cycle. Once the baseline risk list is established, risks must be watched for potential increases in magnitude, and also new risks must be watched for. The project team updates the risks and then perhaps revisits to the decisions made. The resources found to be most at-risk will suggest useful metrics which the administrative and technical implementing organizations should produce, and frequency with which they should be produced. The risk list must be updated at least monthly, throughout implementation.

TOOLS

Tools Currently in Use

Two tools are currently in use at JPL. One is a web-based relational data-base tool that is currently used in the SIRTF and other projects (see figure 8) to do qualitative risk management.

Figure 8 - Web-based Tailorable RM Tool

X2000 Risk Management

Welcome to the X2000 Risk Management System. If you would like to update a Risk item but are locked out, please Ed Konefat 818-354-4125 or ekonefat@pop jpl nasa gov.

Add Risks
View/Modify Risks
View Risks Only
Risk Overall Summary
View Last Revision
JPL Risk Management

X2000 Risk Table Summary - All Risks

		I	M	I	M	I	M
	High	2	2				
Likelihood	Medium			3	3		
	Low					2	2
		Low		Medium		High	
				Impact			

Implementation Risks without Impact Categorization: 0

Implementation Risks without Likelihood Categorization: 0

Mission Risks without Impact Categorization: 0

Mission Risks without Likelihood Categorization: 0

Risks with a Draft status: 22

Summary by Category

Status	Draft	Reviewed	Analyzed	Accepted	Rejected
Active	22	13	1	15	0
Inactive	20	0	0	0	11

It has the following features:

- available on the web to all Project Team members (in and outside JPL) by password
- tailorable
- allows easy risk item data entry by all project team members, while providing risk configuration control by the risk engineer

The other tool is configured for performing the quantitative assessments described above. It is based on EXCEL (see figure 9) and allows the calculations shown to be made as the data are entered. It also incorporates a Monte Carlo routine which allows risk probability distributions to be assessed. This tool is not multi-user.

Figure 9 - Significant Risk List Tool

Simulate Significant Risk List (SRL) - Quantitative Analysis Tool

No	Cat	Stat us	Risk Description	Cost FY99	Cost FY00	Cost FY01	Cost FY02	Cost Ops	Total Cost Cons. $k	Prob	Exp. Cost $k	Mis. Risk	Mis. Risk Prob	Risk Mitigation Approach
			New risk item	0	0	0	0	0	0	1	0			Accept Risk
7			ABC (Radiation)	500	2000	900	300	15000	18700	0.2	3740		0.2	Accept Risk
5			Stellar Reference Unit (availability)	500	8000	7000	0	30000	45500	0.6	27300		0.6	Accept Risk
3			Navigation Software Development	5000	3000	1000	0	6000	15000	0.7	10500		0.7	Accept Risk
1			Stellar Reference Unit (Radiation)	20000	40000	20000	10000	50000	150000	0.5	75000		0.5	Accept Risk
			Expected Values =	Expected Values =							116540			

Finished Monte Carlo Simulation

Goals for Tools

Most Projects are using a qualitative method. NPG 7120.5A says that the primary risks (those in the upper right corner of the risk matrix) must have a quantitative justification. Our approach is to help projects do that by using the web-based platform and adding automated access to a calculating tool like the SRL tool, when needed. The first stage is to allow the quantitative assessment to be done in the web-based environment, with total project risk projections. The second phase, which is a little more distant, would be to use the power of the relational data base tool to perform the trade-off studies, run the calculations, and present the results in a quick user-friendly manner. This would allow risk managers to run many options and find the most attractive solutions.

CONCLUSIONS

This method can be used if the tools can be made so user friendly that they don't get in the way of the users' ability to assess the project risk position. Training in risk management will be needed, but training required to use the tool must be minimal. Several Projects have expressed interest in practical ways of assessing risk against other managed resources, so the interest exists among project managers at JPL.